

INFRARED OBSERVATIONS AND ENERGETIC OUTBURST OF GRS 1915+105

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ABSTRACT

Multiple near-infrared wavelengths observations, carried out since 1993 on the galactic superluminal source of relativistic ejections GRS 1915 + 105, have yielded three important results.

1) The infrared counterpart of GRS 1915 + 105 exhibits various variations in the $1.2\,\mu\text{m} - 2.2\,\mu\text{m}$ band: the strongest are of ~ 1 magnitude in a few hours and of ~ 2 magnitudes over longer intervals of time (Chaty et al. 1996).

2) The infrared properties of GRS 1915 + 105 are strikingly similar to those of SS 433, and unlike those of any other known stellar source in the Galaxy. The absolute magnitudes, colors, and time variabilities of these two sources of relativistic ejections suggest that GRS 1915 + 105, like SS 433, consists of a collapsed object (neutron star or black hole) with a thick accretion disk in a high-mass-luminous binary system (Chaty et al. 1996).

3) During an intense and long-term X-ray outburst of GRS 1915 + 105 in 1995 August, where a pair of radio-emitting clouds emerged from the compact core in opposite directions at relativistic speeds, we observed the time-delayed reverberation of this radio flare/ejection event in the infrared wavelengths. The observed spectrum of the enhanced infrared emission suggests the appearance of a warm dust component (Mirabel et al. 1996a).

Keywords: infrared: stars – ISM: dust, extinction – stars: individual (GRS 1915 + 105), late-type, variables: other – X-rays: bursts.

1. INTRODUCTION

The hard X-ray transient GRS 1915 + 105 was discovered in the constellation of Aquila, on 15 August 1992, by the WATCH all-sky X-ray monitor on board GRANAT (Castro-Tirado et al. 1992). Frequently radiating $\sim 3 \times 10^{38} \text{ erg s}^{-1}$ in the X-rays, at the kinematic distance of $D = 12.5 \pm 1.5 \text{ kpc}$ from the

Sun, GRS 1915 + 105 is one of the most luminous X-ray sources in the Galaxy. Since this source has a fairly hard spectrum with emission up to 220 keV, and a variable spectral index between -2 and -2.8 , observed by BATSE on the Compton Gamma-Ray Observatory (GRO), GRS 1915 + 105 is likely to be a collapsed object, perhaps a black hole in a binary system (Harmon et al. 1994). Thanks to the arcmin location by SIGMA on GRANAT (Finoguenov et al. 1994), Mirabel et al. (1994) discovered its radio counterpart. After the detection of relativistic ejections of plasma clouds with apparent superluminal motions, GRS 1915 + 105 was called the galactic superluminal source (Mirabel & Rodríguez 1994; Mirabel & Rodríguez 1995; Rodríguez & Mirabel 1995).

Following a multiwavelength study of this source, Mirabel et al. (1994) looked for an optical counterpart, but without success, due to interstellar extinction, since GRS 1915 + 105 is located near the galactic plane at $l = 45.37^\circ$, $b = -0.22^\circ$. Nevertheless, the counterpart of GRS 1915 + 105 was discovered at near-infrared wavelengths (Mirabel et al. 1994). Since its detection in June 1993, this infrared counterpart has often been observed in the near-infrared wavelengths, and we report here these multiple observations, trying to determine the light curve of this source over long and short time scales. These observations also allow us to determine the spectrum of the source, and to see how it changes with the luminosity. These studies help to constrain the nature of the source, and also to understand what its environment is, perhaps composed of heated dust. This can be determined by infrared observations, taken during an intense and long-term X-ray outburst in 1995 August, showing the interactions between GRS 1915+105 and its environment.

2. THE OBSERVATIONS OF THE INFRARED COUNTERPART OF GRS 1915 + 105

Mirabel et al. (1994) showed that there is no visual counterpart of GRS 1915 + 105 brighter than

$R = 21$ magnitudes. Using the NTT with a Gunn-z filter on 9 July 1994, we observed a faint counterpart at $\sim 1 \mu\text{m}$, consistent with the $I = 23.4$ magnitudes counterpart reported by Boër et al. (1996). We carried out infrared observations of GRS 1915 + 105 at the European Southern Observatory (ESO) with the ESO/MPI 2.2 m telescope on 4 and 5 June 1993 and from 5 to 8 July 1994 with the IRAC2(b) camera (Mirabel et al. 1994), in the J ($1.25 \mu\text{m}$), H ($1.65 \mu\text{m}$) and K ($2.2 \mu\text{m}$) bands. The typical seeing for these observations was 1.2 arcsec. Follow-up observations were performed at our request by S. Massey at the 3.6 m Canada-France-Hawaii Telescope (hereafter CFHT) on Mauna Kea on 16 August 1994, with the Redeye camera, with a typical seeing of 0.6 arcsec. The data reduction methods of these images are described in Chaty et al. (1996). The J, H and K-magnitudes are given in Table 1.

The variations in the J, H and K-bands, reported in Fig. 1, show that GRS 1915 + 105 exhibits strong short-term variability in the J, H and K-bands, in intervals of less than 24 hours as well as strong long-term variability over intervals from one month to one year. Indeed, the luminosity of GRS 1915 + 105 increased by nearly 1 magnitude in H and K between the nights of 4 and 5 June 1993, and, between 4 June 1993 and 5 July 1994, there was a change of nearly 2 magnitudes in J, 2.5 magnitudes in H, and 2.1 magnitudes in K. From Table 1 it seems that the infrared colors change with luminosity. The rapid increase of 1 magnitude observed in an interval of 24 hours in June 1993 could result from occultation. It is also interesting to note that this rapid variation of the infrared luminosity occurred in a period when the source was strong and showing rapid variations of luminosity in the 8–60 keV energy band observed by WATCH (Sazonov et al. 1994), and in the 20–100 keV energy band observed by BATSE (Harmon et al. 1994).

3. THE LIKELY NATURE OF GRS 1915 + 105, DERIVED FROM THE INFRARED OBSERVATIONS

From the apparent magnitudes in Table 1 we derived the absolute magnitudes, corrected for interstellar extinction, using a visual absorption of $A_v = 26.5 \pm 1$ magnitudes, and the kinematic distance $D = 12.5 \pm 1.5$ kpc. The absorptions in the J, H and K bands are $A_J = 7.1 \pm 0.2$, $A_H = 4.1 \pm 0.2$ and $A_K = 3.0 \pm 0.1$ magnitudes respectively. The infrared emission of GRS 1915 + 105 cannot arise **only** in the photosphere of the secondary star: 1) because of the shape of the spectrum, which cannot be reproduced by photospheric emission from any stellar type (e.g. Koornneef 1983), and 2) because of the rapid variations in luminosity and energy distribution (see Table 1). Therefore, besides the photospheric emission from the secondary, there must be an additional source of infrared emission in GRS 1915 + 105.

The energy distributions of the most well studied galactic X-ray sources are shown in Fig. 2. To derive the absolute magnitudes of SS 433 we assumed the kinematic distance of 4.2 ± 0.5 kpc (van Gorkom et al. 1982) and a visual absorption $A_v = 7.25 \pm 0.25$ magnitudes (Mc Alary & Mc Laren 1980).

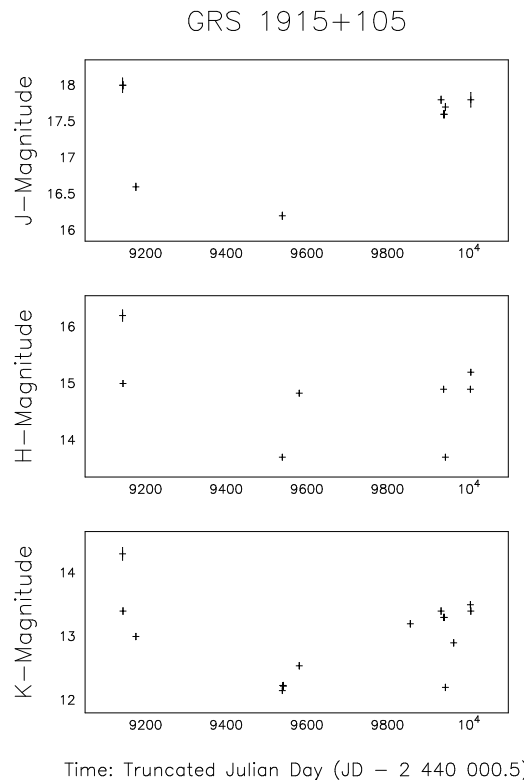


Figure 1: Time variation of J ($1.25 \mu\text{m}$), H ($1.65 \mu\text{m}$) and K-band ($2.2 \mu\text{m}$) luminosities of the source GRS 1915+105 from 4 June 1993 to 17 October 1995.

The estimated errors of the absolute magnitudes of the X-ray sources take into account the uncertainties on the distance and interstellar absorption. Besides the time variations, the infrared absolute magnitudes and colors of GRS 1915 + 105 are strikingly similar to the classic source of relativistic jets SS 433. This similarity in the observed infrared properties suggests that SS 433 and GRS 1915 + 105 are similar systems. The infrared emission of SS 433 arises in a high-mass binary of type late O or early B or Be, with possible contributions of free-free emission from an ionized plasma at $T \sim 7500$ K, an accretion disk, and/or even the jets (e.g. Margon 1984). Within the context of a binary model with an accretion disk, Kodaira et al. (1985) conclude that the observed infrared flux in the SS 433 system comes mostly from an accretion disk around the compact object of the binary system, and that the day-to-day variations may be due to different configurations of disk structures, depending on the mass supply and the internal magnetohydrodynamic balances. Therefore, by analogy with SS 433, GRS 1915 + 105 could be a collapsed object with a thick accretion disk in a hot and luminous high-mass binary.

4. INFRARED OBSERVATIONS OF AN ENERGETIC OUTBURST IN GRS 1915 + 105

During an intense X-ray and radio outburst of GRS 1915 + 105 in 1995 August (Sazonov et al. 1996, Harmon et al. 1995, Foster et al. 1996), we observed a pair of bright radio-emitting clouds with the Very

Table 1: Infrared magnitudes of GRS 1915+105.

Date	UT (hs)	TJD ¹	J (1.25 μ m)	H (1.65 μ m)	K (2.2 μ m)	Telescope	Reference
04/06/1993	1.9	9143.1	$\geq 18 \pm 0.2$	16.2 ± 0.2	14.3 ± 0.2	ESO 2.2m	
05/06/1993	5.0	9144.2	18 ± 0.1	15.0 ± 0.1	13.4 ± 0.1	ESO 2.2m	
07/07/1993		9176	16.6 ± 0.1		13.0 ± 0.1	UKIRT 3.8 m	1
05/07/1994	7.6	9539.3	16.2 ± 0.1	13.7 ± 0.1	12.15 ± 0.08	ESO 2.2m	
06/07/1994	7.5	9540.3			12.23 ± 0.04	ESO 2.2m	
07/07/1994	7.5	9541.3			12.23 ± 0.1	ESO 2.2m	
08/07/1994	5.7	9542.2			12.22 ± 0.1	ESO 2.2m	
16/08/1994	9.6	9581.4		14.83 ± 0.1	12.54 ± 0.1	CFHT 3.6 m	
19/05/1995		9857			13.2 ± 0.1	UKIRT 3.8 m	2
04/08/1995	5.0	9933.2	17.8 ± 0.1		13.4 ± 0.1	ESO 2.2 m	
10/08/1995	9.5	9939.4	17.6 ± 0.1	14.9 ± 0.1	13.3 ± 0.1	UKIRT 3.8 m	
12/08/1995	9.4	9941.4	17.6 ± 0.1		13.3 ± 0.1	Lick 3 m	
15/08/1995	0.0	9944.0	17.7 ± 0.1	13.7 ± 0.1	12.2 ± 0.1	ESO 2.2 m	
04/09/1995	8.7	9964.4			$\geq 12.9 \pm 0.1$	UKIRT 3.8 m	3
16/10/1995	0.1	10006.0		14.9 ± 0.1	13.5 ± 0.1	Kitt Peak 2.1 m	4
17/10/1995	0.1	10007.0	17.8 ± 0.2	15.2 ± 0.1	13.4 ± 0.1	Kitt Peak 2.1 m	4

References:

1: From Castro-Tirado et al. (1993)

2: From Geballe (1995)

3: From Mirabel et al. (1996b)

4: From Eikenberry & Fazio (1995)

¹TJD: Truncated Julian Date (JD - 2 440 000.5)

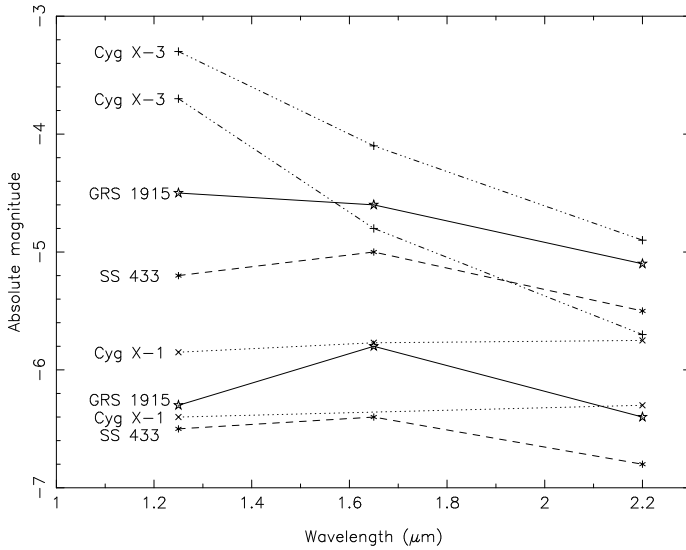


Figure 2: Infrared energy distributions of GRS 1915 + 105, SS 433, Cyg X-1 and Cyg X-3 for the periods of minimum and maximum luminosity.

Large Array, that we were able to follow for an interval of three weeks, emerging from the compact radio core in opposite directions, and at relativistic speeds. In the course of a multiwavelength study, we observed GRS 1915+105 in this period, at near-infrared wavelengths, in the J(1.25 μ m), H(1.65 μ m) and K(2.2 μ m) bands, with various infrared facilities, to study the long term variability of the infrared stellar counterpart of GRS 1915 + 105 (Chaty et al. 1996), and the correlation between the infrared and radio/X-ray emission. We discovered an infrared outburst (Mirabel et al. 1996a), reported in Fig. 3. Due to the time-delayed reverberation of this sudden and major radio flare/ejection event, the infrared outburst was detected between two and five days after the radio outburst. Therefore, the cause of the infrared response to this impulsive event must be at ≥ 2 light-days from the compact object.

The source became redder by $J-K = 1.2$ magnitudes, and brightened by ~ 1 magnitude in K (2.2 μ m). The 1.0 – 2.5 μ m continuum rising to the red suggests the appearance of a warm dust emitting component, and thermal reradiation from heated dust, since there is a cutoff of the enhanced radiation below $\sim 1.45 \mu$ m. Furthermore, a trend towards redder colors as the star becomes brighter has also been observed in SS 433 (Catchpole et al. 1981). The infrared lag due to the light crossing time, and the enhancement of the infrared luminosity emitted in the H and K bands allow us to infer the mass of warm dust surrounding GRS 1915 + 105, and its distance from GRS 1915+105. The thermal energy reradiated from heated dust in the near-infrared was ~ 10 % of the X-ray luminosity of the source, and amounts to about 0.1 % of the typical kinetic energy in the bulk motion of the relativistic ejecta in GRS 1915 + 105. At a distance of 500 a.u. (3 light-days) and with

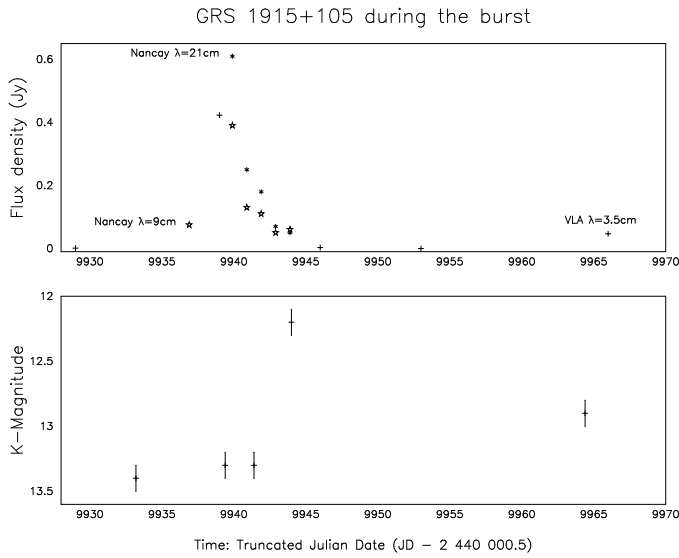


Figure 3: Top: Radio observations of GRS 1915+105 around the 1995 August outburst/ejection event as observed with the VLA at $\lambda = 3.5$ cm, and with the Nanay radiotelescope at $\lambda = 9$ cm and $\lambda = 20$ cm. Bottom: Infrared K ($2.2 \mu\text{m}$) magnitudes of GRS 1915+105. Note the time delay of the infrared brightening relative to the time of peak radio emission.

an X-ray luminosity of $10^{37} \text{ erg s}^{-1}$ we expect an equilibrium dust temperature of only ~ 100 K. We then believe that the near-infrared emission observed could be coming from small grains out of equilibrium with the X-ray field, and that most of the dust is radiating at lower temperatures. Sensitive IR observations at longer wavelengths will be carried out with ISO to test this hypothesis.

5. CONCLUSION

Thanks to many near-infrared wavelengths observations, carried out since 1993 on the galactic superluminal source of relativistic ejections GRS 1915+105, we derived three important results, that give a better understanding of its nature, and lead to a severe constraint on its nature.

We have shown that the infrared counterpart of GRS 1915+105 exhibits short-term variability in intervals of less than 24 hours as well as long-term variability over intervals from one month to one year. We deduced from these infrared observations the fact that the infrared emission of GRS 1915+105 could not arise **only** in the photosphere of the secondary star, and that the infrared absolute magnitudes and colors of GRS 1915+105 were very similar to those of the classic source of relativistic jets SS 433, and unlike those of other well known galactic X-ray sources during minimum and maximum luminosity. Therefore, GRS 1915+105 could be a collapsed object (neutron star or black hole) with a thick accretion disk in a high-mass-luminous binary system. In 1995 August, when in the source GRS 1915+105 was undergoing an intense and long-term X-ray outburst, a pair of radio-emitting clouds emerged from the

compact core in opposite directions, at relativistic speeds. In the infrared wavelengths, we observed the time-delayed reverberation of this radio flare/ejection event. Thanks to the observed spectrum of the enhanced infrared emission, we showed that the appearance of a warm dust component was suggested.

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